JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 11, Number 1 (October 2023):4927-4934, doi:10.15243/jdmlm.2023.111.4927
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Models of Pb distribution and uptake in inundated paddy and maize cropping systems

Lenny Sri Nopriani[1*], Cahyo Prayogo[1], Soemarno[1], Atikah[2], Zaenal Kusuma[1]

[1] Soil Department, Faculty of Agriculture, Brawijaya University, Jl. Veteran 65145 Malang, Indonesia
[2] Department of Chemistry, Faculty of Mathematics and Natural Sciences, Brawijaya University, Jl. Veteran 65145 Malang, Indonesia

*corresponding author: silennysri@yahoo.com

Article history:
Received 1 June 2022
Revised 7 May 2023
Accepted 19 May 2023

Keywords:
environmental contaminant
pollutant
soil adsorption capacity
traffic highway
vehicles emission

Abstract

High-traffic highway crossing agricultural fields impacts the quality of food crops grown on Vertisol agricultural fields in Pasuruan. Lead (Pb) released from the exhaust of motor vehicles into the air can eventually enter the soil and be absorbed by plants. This study aimed to examine the effect of Pb from exhaust motor vehicles emission on the Pb status and its behavior in soil, water, and plants. The study was initiated by conducting a survey to determine the sampling locations in selected inundated paddy and maize cropping systems. A stratified random sampling method was used to collect soil, water, and plant samples. The soil of the study area is dominated by Vertisol, with clay content ranging from 54% to 76%. The soil attributes a high cation exchange capacity ranging from 80.53 meq 100 g^{-1} to 93.57 meq 100 g^{-1}. Pb emitted from 2,913,000 vehicles within four months period that entered the agricultural field was not absorbed by paddy and maize crops. Pb entered the soil in the adsorbed form, and no Pb was observed in the soluble form, so it was not absorbed by the roots. In the paddy field, the total Pb of 84.33% was influenced by pollutant distance. Likewise, in the maize field, 83.18% of total Pb was influenced by pollutant distance. The far the pollutant distance from the agricultural field, the lower its total Pb. Paddy field water is adsorbed onto the colloidal clay, which is dispersed due to inundation and sloughing of the paddy, moving with the clay and then dissolved in the water flow.

To cite this article: Nopriani, L.S., Prayogo, C., Soemarno, Atikah, and Kusuma, Z. 2023. Models of lead (Pb) distribution and uptake in inundated paddy and maize cropping systems. Journal of Degraded and Mining Lands Management 11(1):4927-4934, doi:10.15243/jdmlm.2023.111.4927.

Introduction

Paddy and maize crops are the main and second staple food crops that are grown on agricultural fields along the edge of the main provincial highway of Pasuruan-Probolinggo, East Java, with heavy traffic. The development of transportation facilities that are rapidly increasing and developing around agricultural fields has triggered an increase in the agricultural area adjacent to the high-traffic highway. This condition allows Pb derived from exhaust gases to enter the soil and crops that grow on the side of the highway. The source of Pb pollution on the agricultural field on the side of the highway, among others, comes from the exhaust gases from the combustion process that uses leaded gasoline. Pb that pollutes the air is in the form of solids or particles. Pb mainly comes from burning gasoline additives from vehicles, and the rest are trapped in the exhaust system and engine oil (Wang et al., 2006), and the production of this material will be plummeted soon (Nriagu, 1990). The use of leaded gasoline can affect the availability of Pb in soil, water, and the environment on agricultural fields around the highway (Hettiarachchi and Pierzynski, 2004). A number of studies on the concentration of Pb in soils in India, China, and Indonesia have been carried out. However, most sources of pollutants are derived from industrial wastes with very heavy pollution levels. The problem of heavy metal pollution, especially Pb, is one of the serious environmental problems in both developed and developing countries such as Indonesia. Pb pollution in the soil can harm the ecosystem and the health of living things (Maleki et al., 2014; Xuan et al., 2018). Pb in the agricultural field is closely related to food safety issues and health risks (Hu et al., 2012; Maleki et al., 2014; Xuan et al., 2018). Heavy metals such as Pb can be toxic to plants, animals, and humans when contaminated soil is used for crop production (Arshad, 2010; Hu et al., 2021). Furthermore, the Pb threshold in the soil is 1.0 ppm (García-Esquinas et al., 2013). Various human diseases can arise due to the consumption of food planted in Pb-contaminated soil. Several research results have proven the impact of Pb pollution on human health (Hu et al., 2021). Pb on an agricultural farm can be transferred to the human body through soil-plant-food interactions and can cause some serious defects and abnormalities (Ferguson, 1991). Among the various heavy metals that affect plants, Pb is one of the most dangerous metals and ranks second after arsenic because of its potential toxicity to plants and humans and its occurrence and distribution worldwide (Pourrut et al., 2011).

Research regarding soil Pb pollution originating from the combustion of leaded fuel is rarely informed. Combined leaded fuel will emit 0.09 grams of Pb per 1 km Suganda et al. (2002), Andarani et al. (2009), (Gusnita, 2012), Komarawidjaya (2016; 2017), Yang et al. (2019), Wang et al. (2019) had conducted research on the topic of soil Pb pollution from industrial wastes. Whereas several studies on Pb pollution originating from chemical fertilization and pesticides have been carried out by, among others, Mortvedt (1996) and Mahmood et al. (2014). The high activity of vehicles as a result of the existence of national roads will certainly have an impact on the accumulation of pollutants that are likely to enter the soil and be absorbed by paddy and maize crops nearby. This is caused by the cultivation activities of the two crops mostly carried out along the road section. According to Sembiring and Sulistyowati (2006), most of the Pb in gasoline (70-80%) will be exhausted as particles in the air. Then the amount of Pb contained in dust particles attached to the leaves indirectly indicates the amount of Pb in fuel in the air.

This study aimed to examine and model the spatial distribution of lead (Pb) derived from motor vehicle emission over various distances in inundated paddy and maize cropping systems along the side of the Pasuruan-Probolinggo highway. This study is necessary considering that the agricultural field on the side of the highway in Indonesia is so extensive.

Materials and Methods

Location of study

The locations chosen for this study were paddy fields on the side of the Pasuruan-Probolinggo highway at Gadingrejo Sub-district, Pasuruan City, and maize fields on the side of the Pasuruan-Probolinggo highway at Kraton Sub-district, Pasuruan Regency, East Java. Laboratory analyses of soil, water, and plant samples were carried out in the Soil Chemistry Laboratory of the Soil Department, Faculty of Agriculture, Universitas Brawijaya. This study was conducted from December 2018 to May 2019. The data used in this study were primary data obtained from the field survey and laboratory tests. The sampling locations were spread over 60 locations of paddy fields on the south side of the road and 60 points on maize fields on the above sub-districts' north side of the highway. The population in this study was the area of paddy fields and maize fields within the distance of 10 m, 20 m, and 30 m from the Pasuruan-Probolinggo highway.

Research design

Data of Pb content obtained from laboratory analysis of soil, water, and plant samples were subjected to a two-stage nested experimental design. The methods used in this study were as follows; (1) the distance between the crops field and highway as plot A, i.e., 0-10 m, 10-20 m, and 20-30 m, and (2) the Pb contents in the soil water, and plant tissue Pb as plot B. This study used a completely randomized design with one treatment factor. The treatment was a single factor, namely distance, consisting of three levels of treatment following 0-10 m, 10-20 m, and 20-30 m from the highway. Each level consisted of total Pb and Pb available in soil, water, and crops, each consisting of 60 experimental units. The model for the analysis of variance was as follows:

$$Yij = \mu + \sigma i + \beta(Xij - \tau) + \varepsilon ij$$

The model for variance is as follows:

$$Yij = \mu + \sigma i + \varepsilon ij$$

where:

Yij	=	the observed value of the i-th distance response and the j-th replication
μ	=	general average value
σi	=	effect of treatment i
β	=	regression correction value
Xij	=	the value of the variable to control the i-th error and correct the j-th mean
τ	=	common median value
εij	=	the effect of the error arising from the distance i, to the j-th replication

An F-test of 5% alpha was used to determine the effect of treatment. When there was a significant effect on the observed parameters, then regression and correlation tests were performed to find out how the relationship between the distance and each observed variable.

Soil sampling method

Each soil sample was taken from the location of the paddy field and the maize field. Each location was divided into three sampling points that were distinguished by distance from national highways, namely 10-20 m, 20-30 m, and 30-40 m. Soil samples were taken from 60 random sample points along with the observation variable. A 250 g soil sample is taken at a depth of 0-10 cm from the soil surface. The soil samples were air-dried, ground until fine, and sieved with a 0.2 mm sieve. The sieved sample was taken and weighed as much as 1 g, after which the lead content was analyzed by the Atomic Absorption Spectrophotometry method.

Rice field water sampling method

Water samples were taken from 60 points at each sample plot at the paddy field. Water samples for the lead content (Pb) test were taken from each sample plot of 50 ml. Analysis of Pb content in water using the Atomic Absorption Spectrophotometry method.

Rice and maize plants sampling methods

Analysis of lead content in paddy and maize crops included leaves, stems, roots, grain, and maize kernels. The analysis was carried out as follows: a) Samples of leaves, stems, grain roots, and maize kernels in 1 plant were cut small and mixed into one; b) Plant samples were dried in an oven at 65 ^{O}C for 72 hours; c) After drying the plant samples were ground and sieved with a 425 mesh sieve. Analysis of Pb content in both types of plants was conducted using the Atomic Absorption Spectrophotometry method.

Traffic measurement method

Traffic was measured by counting the number of vehicles of various types of vehicles included in the contributors to lead and particulate pollutants along the highway or the road in the study site area. The types of vehicles counted were buses, trucks, sedans, various types of family vehicles, and motorbikes. The number of each type of vehicle passed was recorded to determine the traffic per hour. The recording was done from 8:00 a.m. to 10:00 a.m., 12:00 a.m. to 00:00 a.m. and 4:00 p.m. to 6:00 p.m. The counting was conducted on weekdays because it was assumed the highway was congested due to routine activities towards Probolinggo, Bali, and vice versa.

Data analysis method

Data analysis regarding the effect of distance between the sample point to the highway (pollutant source) was carried out with ANOVA using Genstat ver 18.00 software. F test for Pb content between distances, and also the interaction of distance and Pb's sample content. This analysis aimed to determine differences in total Pb and its availability to the soil, water, and crops at every measurement distance. Regression and correlation analysis with total Pb as Y and distance as X were carried out to predict Pb levels in soil, water, and crops if the distance from the pollution source was known. Regression analysis was carried out to get the equation of the relationship between the total Pb with pollutant distance, as these approaches have been used in many studies (Aditya et al., 2020; Prayogo et al., 2020). Correlation analysis was performed to measure the degree of closeness of a relationship that occurs between variables, expressed by the value of the correlation coefficient. The correlation coefficient (r) can be defined as a measure of a linear relationship between two variables. Correlation figures range from 0 (no correlation) to 1 (perfect correlation). A correlation number that gets closer to 1 means the correlation is getting closer, while closer to 0 means the correlation is getting weaker (Hasan, 2008).

Result and Discussion

Study locations description

The study location is located along the main highway section of Gempol Pasuruan that crosses Pasuruan Regency. The research area included maize fields located in Bendungan village, Kraton Subdistrict, Pasuruan Regency, and paddy fields located in Karangketuk village, Gadingrejo Subdistrict, Pasuruan City. The farm is located on the side of the road along the main highway along the Kraton Subdistrict of Pasuruan to the north coast of Gadingrejo Subdistrict, Pasuruan City. The area of this study is influenced by: Gempol-Pasuruan corridor on the road section, which is located in the suburbs of Pasuruan with high traffic density. Kraton Highway and Karangketuk Highway, are Gempol-Pasuruan corridor sections. Soil characteristics need to be analyzed to determine the soil type and the influence of physical (texture) and chemical properties (pH, CEC, and organic matter content) of the soil on its ability to adsorb Pb ions. Judging from its physical properties, each of these soils has the same characteristics. The soil characteristics of the experiment are presented in Table 1. Data presented in Table 2 show the average of the highest total Pb of the paddy field of 1.64984 ppm at the distance of 10-20 m and the average of the lowest total Pb of 1.27818 ppm at the distance of 30-40 m. Based on the one-way ANOVA, the calculated F value was greater than the F-table (1091.783>3.047), and the p-value was smaller than α (0.000<0.050). Thus, H0 is rejected, so it can be concluded that there was a significant difference in the average Pb of total land between treatments. From the notation column, the results showed that the soil treatment was 10-20 m with the highest average Total Pb and was significantly different from the treatment distance of 20-30 m and 30-40 m, and the average total Pb of 20-30 m and 30-40 m was also significantly different.

Table 3 shows the average of the highest total Pb of maize field, 1.1228 ppm, at the distance of 10-20 m, and the average of the lowest total Pb 0.2175 ppm, at the distance of 30-40 m. Based on the one-way ANOVA, the calculated F value was greater than the F table (1091.783>3.047), and the p-value was smaller than α (0.000<0.050). Thus, H0 is rejected, so it can be concluded that there was a significant difference in the average Pb of total land between treatments. From the notation column, the results showed that the soil treatment was 10-20 m with the highest average of total Pb and was significantly different from the treatment distance of 20-30 m and 30-40 m, and the average total Pb of 20-30 m and 30-40 m was also significantly different. The results of linear regression analysis showed that total Pb in the soils was strongly correlated with the distance (Table 4 and Figure 1). The distance had a positive effect on the paddy field water total Pb (Table 4 and Figure 2). The value of the regression coefficient (R^2) was 0.6904, indicating that the paddy field water total Pb was influenced by distance by 69.04%. The farther the distance from the highway, the higher the paddy field water total Pb. The increase in Pb content in paddy field water is based on the distance from the highway due to the direction of paddy field water flow away from the source of pollution, meaning that Pb in paddy field water is adsorbed on the colloidal clay that dissolves in the water.

Table 1. Characteristics of Vertisol in Gadingrejo and Kraton, Pasuruan.

No.	Parameter	Gadingrejo Rice Field	Kraton Maize Field
1.	Texture Class	Clay	Clay
	Sand (%)	10	7
	Silt (%)	33	27
	Clay (%)	54	76
2.	Structure	Angular Blocky	Angular Blocky
3.	Bulk Density (g cm^{-3})	0.91	0.93
4.	Particle Density (g cm^{-3})	2.35	2.23
5.	Porosity (%)	63.2	56.4
6.	Permeability (cm $hour^{-1}$)	0.76	0.52
	Criteria	Quite Slow	Quite Slow
7.	COLE Value	0.19	0.19
	Criteria	High	High
8.	CEC (meq 100 g^{-1})	80.53	93.97
	Criteria	Very High	Very High
9.	pH	6.8	6.9
	Criteria	Normal-Low Acid	Normal-Low Acid
10.	Organic C (%)	2.09	2.62
	Organic Matter (%)	3.57	3.63
	Criteria	High	High

Table 2. The average of total Pb and available Pb in soil, Pb in water, Pb in paddy tissue in different treatments.

Treatment	Average of total Pb in soil (ppm)	Available Pb in soil (ppm)	Pb in paddy water field (ppm)	Pb in paddy tissue (ppm)
S10-20	1.64984 b	0	0.2641 a	0
S20-30	1.35632 a	0	0.4149 b	0
S30-40	1.27818 a	0	0.4815 c	0

Table 3. The average of total Pb and available Pb in soil, Pb in water, Pb in maize tissue in different treatments.

Treatment	Average of total Pb in soil (ppm)	Available Pb in soil (ppm)	Pb in maize water field (ppm)	Pb in maize tissue (ppm)
LK10-20	1.1228 c	0	0	0
LK20-30	0.5921 b	0	0	0
LK30-40	0.2175 a	0	0	0

Description: LK10-20: 10-20 m field and road distance, LK20-30: 20-30 m field and road distance, LK30-40: 30-40 m field and road distance.

Table 4. Regression and correlation analyses between distance and total Pb.

Observed Variable	Asymptotic Equation	R^2	R	Correlation
Total Pb in soil	$Y=1.229+2{,}294^{-0{,}094x}$	0.843	-0.61	Very Strong Negatively
Pb in paddy water field	$Y=-0.495-1.783^{-0.175x}$	0.690	0.817	Very Strong Positively
Pb in maize tissue	$Y=0.21407 + 4.0451^{-0.0117x}$	0.831	-0.898	Very Strong Negatively

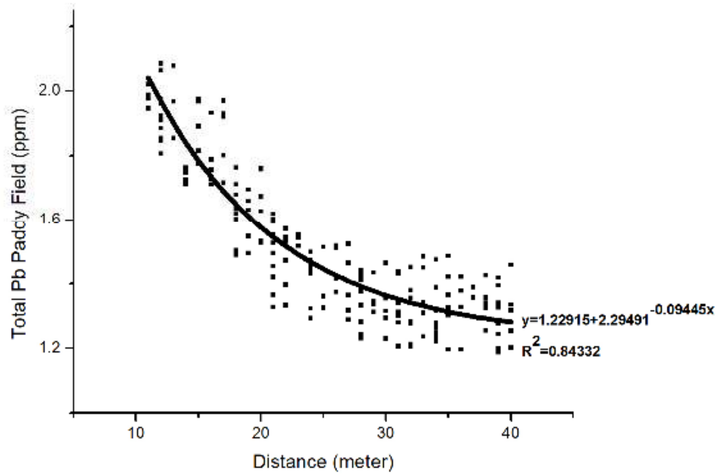

Figure 1. The asymptotic curve of the relationship between distance and paddy field's total Pb.

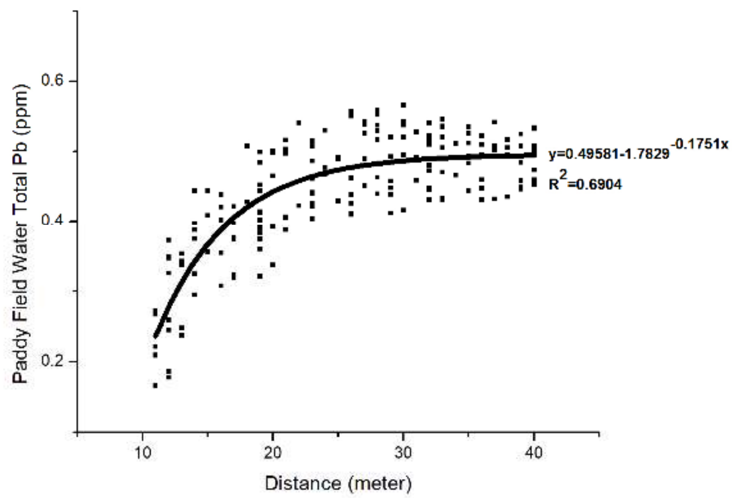

Figure 2. The asymptotic curve of the relationship between distance and paddy field water's total Pb.

The paddy field water moves away from the highway. This also relates to the colloidal system of paddy field, where the mixing of soil with liquid occurs in the process of inundation of paddy fields. In the process of inundation, the particles of soil are dispersed and spread evenly into the water. This process is called the disperse system (De Datta, 1981). The dispersed clay binds Pb and carries it along with the water flow away from the source of pollution.

The results of linear regression analysis presented in Table 4 and Figure 3 showed that distance has a negative effect on the maize field total Pb. The value of the regression coefficient (R^2) was 0.8318, indicating that 83.18% of the variation of the maize field total Pb was influenced by distance. The farther the distance from the highway, the lower the maize field total Pb. From these equations, we can see the coefficient of determination (R^2) of 0.368-0.806. This means the relationship between soil Pb concentration and distance is interpreted as a strong correlation. Distance to the highway gives an influence of 36-80% to the concentration of Pb in oil. The distance of the highway strongly influences the total Pb content in the soil. The farther away from the Pb highway, the total paddy field and maize fields decrease. Pb in paddy field water is increasing with the distance from the highway. Several factors, including soil type and soil conditions, influence the content of heavy metals in the soil. In addition, heavy metals enter the soil environment through chemicals that directly affect the soil, dust accumulation, rain, soil erosion, and waste disposal (Darmono, 2006).

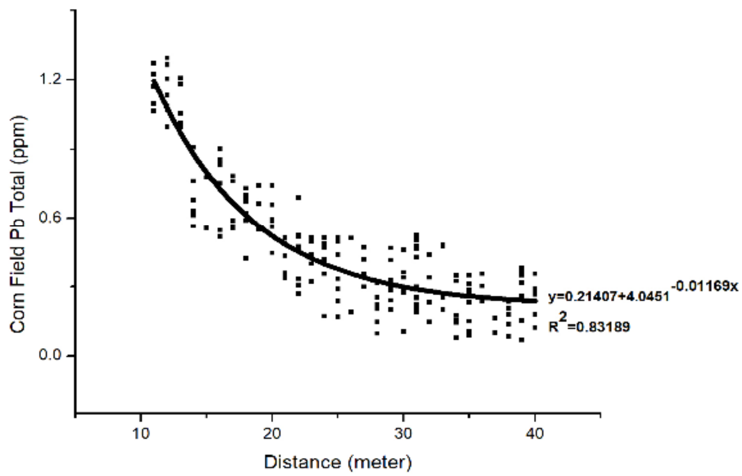

Figure 3. The asymptotic curve of the relationship between distance and maize field's total Pb.

Research on the spatial distribution of heavy metal in soil and crop are limited and becoming an interesting topic in the last ten years of study, which cover a wide range of interest (Meleki et al., 2014; Xuan et al., 2018; Hani et al., 2010). The result of the linear regression of sources of Pb from the motor vehicle has never been informed. The previous finding showed that the source of Pb is mainly from small industries/workshop nearby farm which is dominated by coriander, dill, and reddish, which accumulated 0.4 mg Pb kg^{-1}. This value was still below the maximum allowable standard (Meleki et al., 2014).

The result also indicated that spatially, the lowest Pb was concentrated in the middle of the farm (Meleki et al., 2014). On the other hand, the spatial distribution of heavy metals, including Pb, in vegetable soil in China corresponded to the heavy use of phosphate fertilizer (Xuan et al., 2018). A high concentration of Pb in agricultural land determined crop yield (Hani et al., 2010), whereas the distribution of Pb in this area followed an inverted U shape curve in the south-north direction. The lowest value was in the southern part of the land (Hani et al., 2010). Different rate applications or organic manure were also suspected to affect the spatial distribution of Pb in the soil. The pattern of Pb in the soil varies from one site to another, depending on many factors such as massive use of fertilizer, slope position of organic matter, and soil type).

In this study, the site is situated in flat conditions (0-10%), and linear regression was used to determine the relationship between sampling location and Pb status. Instead of using correlation and regression analysis, a new technique for examining the spatial distribution of Pb in soil adopted a semivariogram model (Hani et al., 2010; Hu et al., 2021). High clay content and very high CEC values of Vertisol soil type cause high adsorption levels of Pb so that Pb becomes unavailable both in paddy and maize fields of Vertisol in Kraton-Pasuruan. The amount of lead released into the atmosphere is only 20%, which is widely dispersed. The distribution distance depends on particle size, while emissions from motor vehicles, as much as 20-60%, remain 25 m behind the highway. Particles with a diameter of 3 µm will settle by gravity within a radius of 6-8 meters, while particles with a diameter of 5-50 µm settle by gravity within a radius of 12 m (Nriagu, 1979). Lead, in some cases, is identified to be difficult to dissolve and enter the soil and accumulate in the ecosystem where the lead is deposited so that lead is difficult to remove.

Based on the results of the analysis of lead content in paddy and maize above, information is obtained that the distance function from the emission source has no effect on both paddy and maize crops. Treshow and Anderson (1989) stated that the amount of lead in the air was influenced by the volume or density of traffic, distance from the highway, industrial area, engine speed, and wind direction. Besides that, the amount of lead content in plants is influenced by sedimentation and collisions that occur. According to Gidding (1973), particles emitted by motorized vehicles measure between 0.004-1.0 µm. Before falling into the water, soil, and plants, Small lead will float for a few moments in the air free. The sedimentation process causes lead fall due to the force of gravity and precipitation associated with rain. Lead from pollutant sources is not absorbed by plants so lead in the Vertisol of Pasuruan is still within safe limits for agricultural land and food crops.

Conclusions

Lead (Pb) derived from motor vehicle emission is 84.33% influenced by distance. Likewise, in the maize field, the total Pb of 83.18% is influenced by the distance from the highway. The further the distance from the highway, the lower the total Pb level. Pb, which was detected on paddy field water, is adsorbed on the colloidal clay, which is dispersed due to inundation and sloughing of the paddy, moving with the clay particle. This phenomenon was not detected under the maize cropping system. Fortunately, the level of Pb in soil or even in water solution was not absorbed by the crop yet, so it can be assumed that the level of Pb is still below the limits. However, the level of Pb under the paddy system was much higher than in the maize cropping system. The clay content of Vertisol is suspected to be an absorbance material of Pb for becoming available, absorbed, and harmful to crops or even further affecting yields.

Acknowledgments

The authors thank all laboratory and field staff who support these activities and the Faculty of Agriculture Brawijaya University for providing internal funding for this study.

References

Aditya, H.F., Gandaseca, S., Rayes, M.L., Karam, D.S., Prayogo, C. and Nugroho, G.A. 2020. Characterization, changes in soil properties and vegetation distribution as affected by topography in Ayer Hitam Forest Reserve, Selangor, Peninsular Malaysia. *AGRIVITA, Journal of Agricultural Science* 42 (3):548-562, doi:10.17503/agrivita.v42i3.2617.

Andarani, P. and Roosmini, D. 2009. Profile of Heavy Metal Pollution (Cu, Cr, dan Zn) on Surface Water and Sediment surrounding Textile Industry of PT X (Cikijing River), Faculty of Civil and Environmental Engineering, ITB (*in Indonesian*).

Arsyad, S. 2010. *Soil and Water Conservation*. Second Edition. IPB Press Bogor (*in Indonesian*).

Darmono. 2006. *The Environment and Pollution: Its Relationship with the Toxicology of Metal Compounds*. UI Press. Jakarta (*in Indonesian*).

De Datta, S.K. 1981. *Principle and Practices of Rice Production*. John Willey and Sons, Inc. New York. 618p.

Fergusson, J.E. 1991. *The Heavy Elements: Chemistry, Environmental Impact and Health Effects.* Pergamon Press, Oxford-NY-Seoul-Tokyo.

García-Esquinas, E., Pérez-Gómez, B., Fernández-Navarro, P., Fernández, M.A., de Paz, C., Ana Pérez-Meixeira, M., Gil, E., Iriso, A., Sanz, J.C., Astray, J., Cisneros, M., de Santos, A., Asensio, A., García-Sagredo, J.M., Frutos García, J., Vioque, K., López-Abente, G., Pollán, M., González, M.J., Martínez, M. and Aragonés, N. 2013. Lead, mercury, and cadmium in umbilical cord blood and its association with parental epidemiological variables and birth factors. *BMC Public Health* volume 13, Article number:841, doi:10.1186/1471-2458-13-841.

Giddings, J.C. 1973. *Chemistry, Mans and Environmental Changes: An Integrated Approach*. New York: Canfield.

Gusnita, D. 2010. Emission Analisys of CO, HC and Opacity-Result of Pikced Test of Motor Vehicle in DKI Jakarta region, Proceeding of National Seminar, LAPAN, Bandung (*in Indonesian*).

Hani, A., Pazira, E., Manshouri, M., Kafaky S.B. and Tali, M.G. 2010. Spatial distribution of mapping of risk elements pollution in agricultural soils of southern Tehran, Iran. *Plant and Soil Environment* 56(6):288-296, doi:10.17221/16/2010-PSE.

Hasan, M.I. 2008. *Research Data Analysis using Statistics*. PT. Bumi Aksara, Jakarta (*in Indonesian*).

Hettiarachchi, M.G. and Pierzynski, G.M. 2004. Soil lead bioavailability and in situ remediation of lead-contaminated soils: a review. *Environmental Progress* 23(1):78-93, doi:10.1002/ep.10004.

Hu, S., Chen, X., Jing, F., Liu, W. and Wen, W. 2021. An assessment of spatial distribution and source identification of five toxic heavy metals in Nanjing, China. *Environmental Engineering Research* 26(3):200135, doi:10.4491/eer.2020.135.

Hu, Y., Wang, C., Song, Z., Chen, M., 3, Ding, L., Liang, X., Bi, X., Li, Z., Li, P. and Zheng, W. 2021. Heavy Metal in Rice and Vegetable and Human Exposure near a Large Pb/Zn Smelter in Central China. *International Journal of Environmental Research and Public Health* 18(23):12631, doi:10.3390/ijerph182312631.

Komarawidjaja, W. 2016. The distribution of liquid waste textile industry and their impact on several regions of Rancaekek-Bandung. *Jurnal Teknik Lingkungan* 17(2):118-125, doi:10.29122/jtl.v17i2.1045 *(in Indonesian)*

Komarawidjaja, W. 2017. The exposure of industrial liquid waste containing heavy metals to paddy fields of Jelegong, Rancaekek-Bandung, *Jurnal Teknik Lingkungan* 18(2):173-181, 10.29122/jtl.v18i2.2047 (*in Indonesian*).

Mahmood, A., Malik, R.N., Li, J. and Zhang, G. 2014. Human health risk assessment and dietary intake of organochlorine pesticides through air, soil and food crops (wheat and rice) along two tributaries of river Chenab, Pakistan. *Food and Chemical Toxicology* 71:17e25, doi:10.1016/j.fct.2014.05.008.

Maleki, A., Amini, H., Nazmara, S., Zandi, S. and Mahvi, A.H. 2014. Spatial distribution of heavy metals in soil, water, and vegetables of fram in Sanandaj, Kurdistan, Iran. *Journal of Environmental Health Science and Engineering* 12(1):136, doi:10.1186/s40201-014-01360.

Mortvedt, J.J. 1996. Heavy metal contaminants in inorganic and organic fertilizers. *Fertility Research* 43:55e61, doi:10.1007/BF00747683.

Nriagu, J.O. 1979. Global inventory of natural and anthropogenic emissions of trace metals to the atmosphere. *Nature* 279:409-411, doi:10.1038/279409a0.

Nriagu, J.O. 1990. The rise and fall of leaded gasoline. *Science of The Total Environment* 92:13-28, doi:10.1016/0048-9697(90)90318-O.

Pourrut, B., Shahid, M., Dumat, C., Winterton, P. and Pinelli, E. 2011. *Lead Uptake, Toxicity, and Detoxification in Plants Reviews of Environmental Contamination and Toxicology* 213:113-36, doi:10.1007/978-1-4419-9860-6_4.

Prayogo, C., Prastyaji, D., Prasetya, B. and Arfarita, N. 2020. Structure and composition of arbuscular mycorrhizal fungi under different farmer management of coffee and pine agroforestry system. *AGRIVITA, Journal of Agricultural Science* 43(1):146-163, doi:10.17503/agrivita.v1i1.2639.

Sembiring, E. and Sulityawati, E. 2006., Pb accumulation and its effect on the condition of *Swietenia macrophylla* King leaves. Paper presented at the 2006 National Seminar on Environmental Research in Higher Education, at the Bandung Institute of Technology Campus 17-18 Juli 2006 (*in Indonesian*).

Suganda, H., Setyorini, D., Kusnadi, H., Saripin I. and Kurnia, U. 2002. Evaluation of industrial waste pollution for the preservation of paddy field resources. Center for Soil and Agro-climate Research and Development. Agricultural Research and Development Agency (*in Indonesian*).

Treshow, M. and Anderson, F.K. 1989. *Plant Stress from Air Pollution*. New York: John Willey & Sons, Ltd. Chichester.

Wang, C., Zhan, J., Bai, Y., Chu, X. and Zhang, F. 2019. Measuring carbon emission performance of industrial sectors in the Beijing-Tianjin-Hebei region, China: a stochastic frontier approach. *Science of The Total Environment* 685:786-794, doi:10.1016 /j.scitotenv.2019.06.064.

Wang, W., Liu, X.D., Zhao, L.W., Guo, D.F, Tian, X.D. and Adams, F. 2006. Effectiveness of leaded petrol phase-out in Tianjin, China based on the aerosol lead 690 concentration and isotope abundance ratio. *Science of The Total Environment* 364:175-187, doi:10.1016/j.scitotenv.2005.07.002

Xuan, B., Lu, X., Wang, J., Cai, X., Duan, Z., Hu, F., Wang, K. and Li., D. 2018. Spatial distribution characteristic and assessment of total and available heavy metal in karst peri urban vegetable soil. *IOP Conference Series: Material Science and Engineering* 392:042022, doi:10.1088/1757-899X/392/4/042022.

Yang, W., Wang, D., Wang, M., Zhou, F., Huang, J., Xue, M., Dinh, Q.T. and Liang, D., 2019. Heavy metals and associated health risk of wheat grain in a traditional cultivation area of Baoji, Shaanxi, China. *Environmental Monitoring and Assessment* 191(7):428, doi:10.1007/s10661-019-7534-9.